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LEVEL II

(6) NOTE ON COMPUTER GRAPHICS FOR MAXIMUM ENTROPY SPECTRAL ANALYSIS*

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NOTE ON COMPUTER GRAPHICS FOR MAXIMUM ENTROPY SPECTRAL ANALYSIS

Summary: Computer graphics provides an effective three-dimensional display of power spectral density for varying parameters. Based on the software we have developed, the computer-graphics display is presented for Burg's maximum entropy spectral analysis and Fougere's (nonlinear) maximum entropy spectral analysis. The significantly greater dynamic range of the Fougere's spectrum clearly illustrates the superiority of the Fougere's method. The graphics software listing is provided in the Appendix of the report.

A1

Spectral Display of Sunspot Numbers

Fig. 1a is a plot of January Zürich sunspot numbers for 200 data points for the period 1779 to 1978. Fig. 1b is the display of Burg's spectrum of Fig. 1a for filter weights 10 to 58 and frequency interval 0.05 to 0.15 cycles per year. All spectrum plots are in logarithmic scale with base 10. The three numbers on the top of the photo are A= minimum spectral magnitude, B= maximum spectral magnitude, and C= difference between B and A, in log scale. For Fig. 1b, A=2.798, B=5.113, C=2.315. In all graphical displays of the report, 450 points are used for computation in frequency and weight number axes even though only 225 points are actually used for display (See Appendix).

Fig. 2a is a section of 25 data points from Fig. 1a to cover the period 1954-1978. Fig. 2a is the Burg's spectra for filter weights of 1 to 17. The dynamic range is A=6.281, B=14.424,

C=8.143. Fig. 2c is the Fougere's spectra of Fig. 2a for filter weights of 1 to 17. The dynamic range is A=4.403, B=17.225 and C=12.822. The increase in dynamic range by using the Fougere's method is about 46.8dB.

Spectral Display of Sinewaves

Figure 3a is the sinewave considered which is given by the equation

$$x(t) = \sin(2 \ ft + \theta) + SNR \times n(t)$$

with DT(sampling period)=0.05, f=1, $\theta=45^{\circ}$, SNR=50dB, and n(t) is zero mean, unit variance Gaussian noise. 25 data points are used in spectral analysis. Fig. 3b is the Burg's spectra for filter weights of 1 to 17 and frequency interval of 0 to 2.7 Hz. The dynamic range is A=-14.108, B=3.085, C=17.193. Fig. 3c is the Fougere's spectra for the same filter weights and frequency interval. The cynamic range is A=-14.584, B=10.353, C=24.937. The increase in dynamic range of the spectral magnitude by using the Fougere's method is about 77.5dB.

Useful References:

1. C. H. Chen, "Spectral resolution of Fougere's maximum entropy spectral analysis", Proc. of the IEEE, June 1981.
2. C. H. Chen, J. Chen and C. Yen, "A Minicomputer implementation of Fougere's maximum entropy spectrum analysis method", Technical Report, SMU-EE-TR-80-7, August 20, 1981.

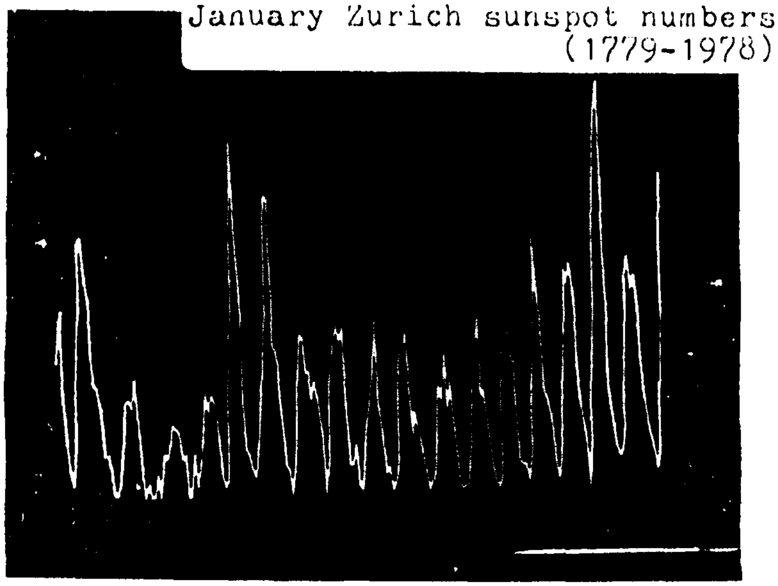


Fig. 1a

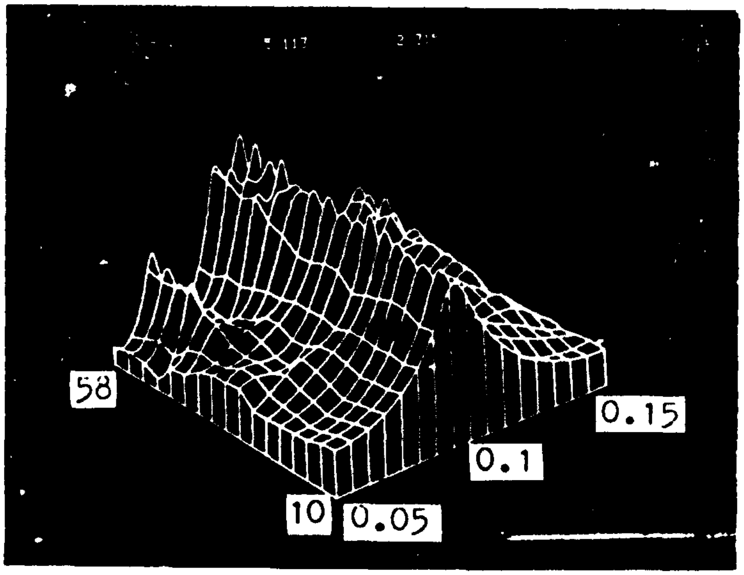


Fig. 1b

January Zurich sunspot numbers
(1954-1978)

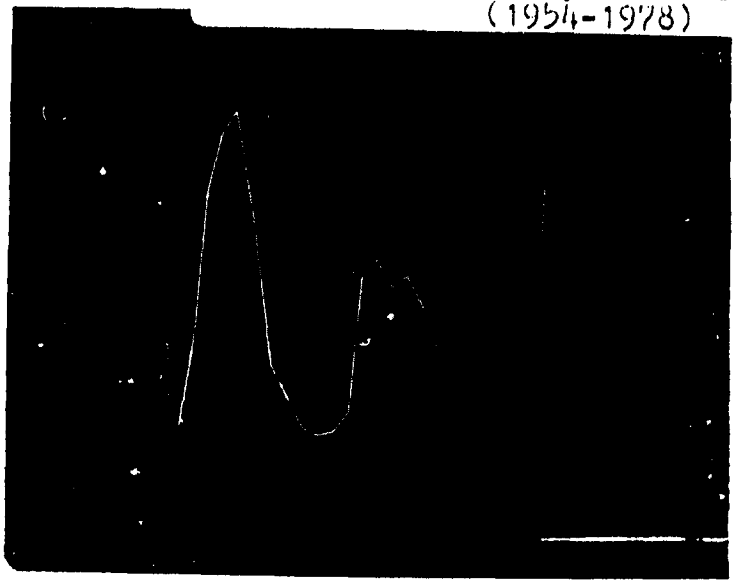


Fig. 2a

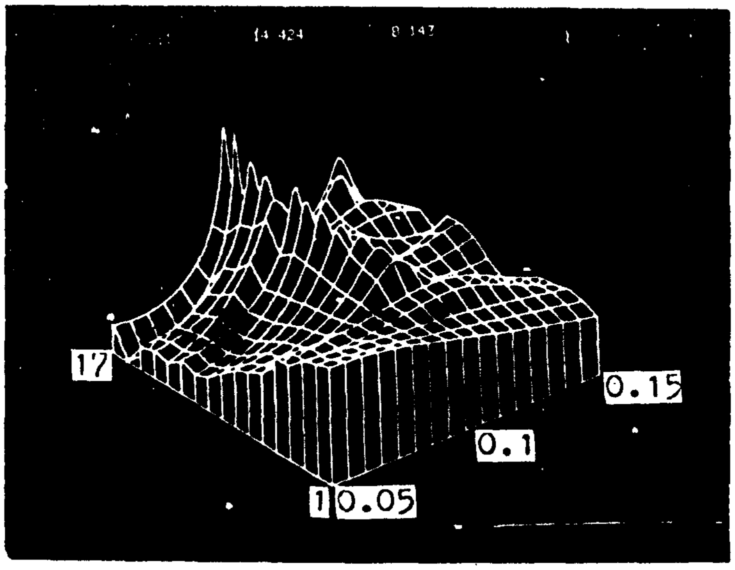
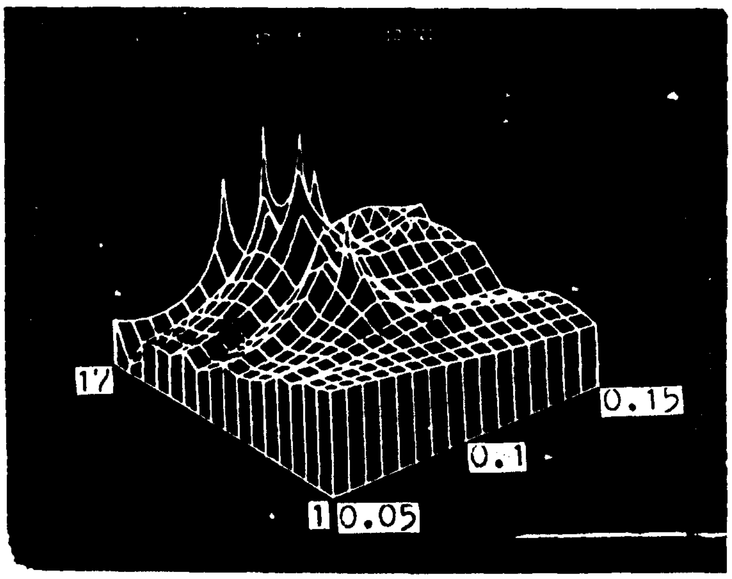


Fig. 2b



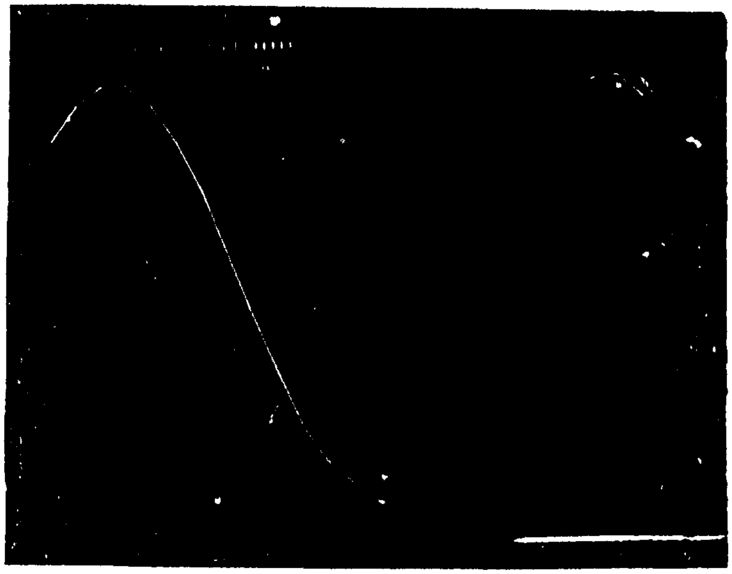


Fig. 3a

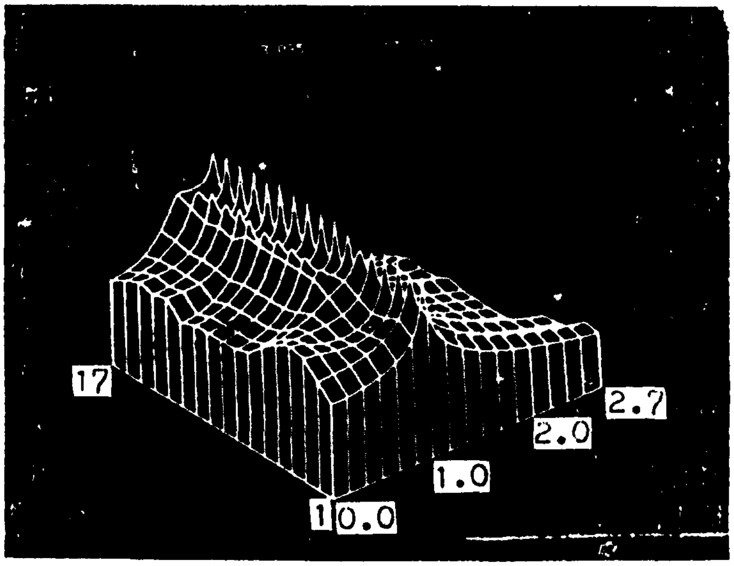


Fig. 3b

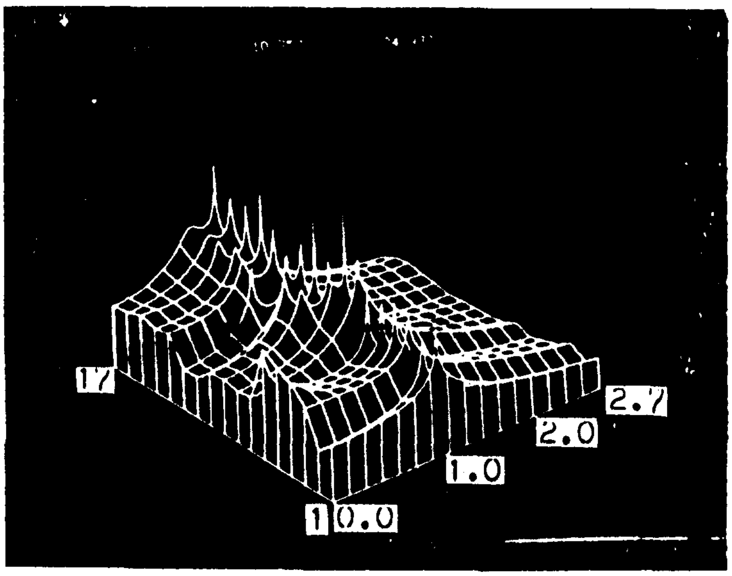


Fig. 3c

APPENDIX

FORTRAN V04.13   03:33:43   22-MAR-81   PAGE 1

```
      C
      C         NAME. CMCF [200,200]
      C
                REAL Y(225),YY(17),X(225)
                INTEGER IX(6),IY(6),IX1(6),IY1(6),IXX(4),IYY(4)
                INTEGER IYC(225),XY(17,225),IX2(2),IY2(2),EN
                DATA IX/445,445,882,882,98,98/
                DATA IY/73,349,229,505,284,560/
                DATA IX1/445,445,98,98,882,882/
                DATA IY1/73,349,284,560,229,505/
      C
      C         IN THIS CASE I CREATE A HORIZONTAL FILE IN FILE 7
      C         AND A VERTICAL FILE IN FILE 3
      C         1ST STEP: TO CREATE A VERTICAL FILE WHICH HAS LN LINES
      C                   AND EN PTS OF ONE LINE
      C
                LN=17
                EN=225
                IBN=EN*2
                NFU1=7
                NFU2=3
                LSG=LN-1
                IQ=(EN-1)/LSG
                IF((IQ*LSG+1).NE.EN)GO TO 270
                DO 60 I=1,LN
                DEFINE FILE NFU1(LN,IBN,U,LINE)
                DO 30 J=1,LN
                LINE=J
                READ(NFU1'LINE)Y
                K=(I-1)*IQ+1
                YY(J)=Y(K)
       30       CONTINUE
                END FILE NFU1
                DO 50 LL=1,LSG
                KK=LL+1
                DIS=(YY(KK)-YY(LL))/IQ
                DO 40 MM=1,IQ
                NN=(LL-1)*IQ+MM
                X(NN)=YY(LL)+DIS*FLOAT(MM-1)
       40       CONTINUE
       50       CONTINUE
                X(EN)=YY(LN)
                DEFINE FILE NFU2(LN,IBN,U,INDEX)
                INDEX=I
                WRITE(NFU2'INDEX)X
                END FILE NFU2
       60       CONTINUE
                CALL BELL
      C
      C         2ND STEP: TO NORMALIZE THE BOTH OF TWO FILES
      C
                DEFINE FILE NFU1(LN,IBN,U,LINE)
                LINE=1
                READ(NFU1'LINE)Y
                EMIN=Y(1)
```

```
      FMAX=Y(1)
      DO 80 I=1,LN
      LINE=I
      READ(NFU1'LINE)Y
      DO 70 J=1,EN
      IF(Y(J).GT.FMAX)FMAX=Y(J)
      IF(Y(J).LT.FMIN)FMIN=Y(J)
70    CONTINUE
80    CONTINUE
      END FILE NFU1
      FFMAX=FMAX-FMIN
      CALL NEWPAG
      WRITE(6,90)FMIN,FMAX,FFMAX
90    FORMAT(1X,3F15.3)
      DO 120 L=1,2
      IF(L.EQ.1)NFU=NFU1
      IF(L.EQ.2)NFU=NFU2
      DO 110 I=1,LN
      DEFINE FILE NFU(LN,IBN,U,LINE)
      LINE=I
      READ(NFU'LINE)Y
      END FILE NFU
      DO 100 J=1,EN
      Y(J)=Y(J)-FMIN
100   CONTINUE
      DEFINE FILE NFU(LN,IBN,U,IDX)
      IDX=I
      WRITE(NFU'IDX)Y
      END FILE NFU
110   CONTINUE
120   CONTINUE
      CALL BELL
C
C     3RD STEP: TO CHANGE DATA VALUES TO ABSOLUTE COORDINATE VALUES
C
      IH=IY(2)-IY(1)
      DO 140 L=1,2
      IF(L.EQ.1)NFU=NFU1
      IF(L.EQ.2)NFU=NFU2
      DO 130 M=1,LN
      DEFINE FILE NFU(LN,IBN,U,LINE)
      LINE=M
      READ(NFU'LINE)Y
      END FILE NFU
      CALL MAXMIN(Y,YMAX,YMIN,EN)
      RATE=YMAX/FFMAX
      IF(NFU.EQ.NFU1)CALL CNCO(IX,IY,IXX,IYY,M,RATE,LSG,IH)
      IF(NFU.EQ.NFU2)CALL CNCO(IX1,IY1,IXX,IYY,M,RATE,LSG,IH)
      CALL CRDT1(IYC,Y,EN,IXX(1),IXX(3),IYY(1),IYY(2),IYY(3),M)
      DEFINE FILE NFU(LN,IBN,U,LINE)
      LINE=M
      WRITE(NFU'LINE)(IYC(NNN),NNN=1,EN)
      END FILE NFU
130   CONTINUE
140   CONTINUE
      CALL BELL
```

```
      C
      C        4TH STEP: TO MOVE OUT THE HIDDEN POINTS
      C
               DO 220 L=1,2
               IF(L.EQ.1)NFU=NFU1
               IF(L.EQ.2)NFU=NFU2
               DEFINE FILE NFU(LN,IBN,U,LINE)
               DO 160 I=1,LN
               LINE=I
               READ(NFU'LINE)(IYC(NNN),NNN=1,EN)
               DO 150 J=1,EN
      150      XY(I,J)=IYC(J)
      160      CONTINUE
               END FILE NFU
               DO 190 I=2,LN
               KI=I-1
               DO 180 K=1,KI
               ITT=INT(FLOAT(I-K)*RATE)
               NN=ITT+1
               IF(NN.GT.EN)GO TO 180
               DO 170 N=NN,EN
               MM=N-ITT
               IF(MM.LE.0)GO TO 170
               IF(XY(I,N).LT.0)GO TO 170
               IF(XY(I,N).GT.XY(K,MM))GO TO 170
               XY(I,N)=-XY(I,N)
      170      CONTINUE
      180      CONTINUE
      190      CONTINUE
               DO 210 I=1,LN
               LINE=I
               DO 200 J=1,EN
      200      IYC(J)=XY(I,J)
               WRITE(NFU'LINE)(IYC(NNN),NNN=1,EN)
      210      CONTINUE
               END FILE NFU
      220      CONTINUE
               DO 230 L=1,15
               CALL BELL
      230      CONTINUE
      C
      C        5TH STEP: TO DRAW THE 3-DIMENSION PICTURE ON THE SCREEN
      C
               DO 260 L=1,2
               IF(L.EQ.1)NFU=NFU1
               IF(L.EQ.2)NFU=NFU2
               DO 240 I=1,EN
      240      Y(I)=FLOAT(I)
               DEFINE FILE NFU(LN,IBN,U,LINE)
               DO 250 M=1,LN
               LINE=M
               READ(NFU'LINE)(IYC(NNN),NNN=1,EN)
               IF(NFU.EQ.NFU1)CALL CNCO1(IX,IY,IX2,IY2,M,LSG)
               IF(NFU.EQ.NFU2)CALL CNCO1(IX1,IY1,IX2,IY2,M,LSG)
               CALL LLKBP(Y,IYC,EN,IX2(1),IX2(2),IY2(1),IY2(2),M)
      250      CONTINUE
```

```
0147                  END FILE NFO
0148        260       CONTINUE
0149        270       CALL BELL
0150                  CALL EXIT
0151                  END

          ROUTINES CALLED
          FLOAT , BELL   , NEWPAG, MAXMIN, CNCO   , CRDTI , INT
          CNCO1 , CLRBF  , EXIT

          OPTIONS =/OP:2

          BLOCK        LENGTH
          MAIN      10580   (051250)*

          **COMPILER ------- CORE**
             PHASE        USED  FREE
          DECLARATIVES  00622 14756
          EXECUTABLES   01183 14195
          ASSEMBLY      01821 13597
```

```
      SUBROUTINE CNC01(IX,IY,IXX,IYY,I,KK)
      INTEGER IX(1),IY(1),IXX(1),IYY(1)
      DX=FLOAT(IX(5)-IX(1))
      DY=FLOAT(IY(5)-IY(1))
      DZ=SQRT(DX*DX+DY*DY)
      DZS=DZ/FLOAT(KK)
      TH=ATAN2(DY,DX)
      A=COS(TH)
      B=SIN(TH)
      IXX(1)=INT(FLOAT(IX(1))+FLOAT(I-1)*A*DZS)
      IYY(1)=INT(FLOAT(IY(1))+FLOAT(I-1)*B*DZS)
      IXX(2)=INT(FLOAT(IX(3))+FLOAT(I-1)*A*DZS)
      IYY(2)=INT(FLOAT(IY(3))+FLOAT(I-1)*B*DZS)
      RETURN
      END
```

```
ROUTINES CALLED:
FLOAT , SQRT   , ATAN2 , COS    , SIN    , INT

OPTIONS =/OP:2

BLOCK       LENGTH
CNC01   384     (001400)*

**COMPILER ----- CORE**
   PHASE        USED  FREE
DECLARATIVES 00622 14756
EXECUTABLES  00863 17515
ASSEMBLY     01097 18931
```

```
FORTRAN V02.13                    03:41:22     22-MAR-81     PAGE    1

              SUBROUTINE CRD11(IY,Y,NPT,IX1,IX2,IY11,IY12,IY21,KK)
              DIMENSION Y(NPT),IY(NPT)
              CALL MAXMIN(Y,YMAX,YMIN,NPT)
              YMIN=0.
              YS=FLOAT(IY12-IY11)/(YMAX-YMIN)
              IY(1)=INT((Y(1)-YMIN)*YS+.5)+IY11
              XX=FLOAT(IX2-IX1)
              YY=FLOAT(IY21-IY11)
              TH=ATAN2(YY,XX)
              R=SQRT(XX*XX+YY*YY)
              RS=R/FLOAT(NPT-1)
              B=SIN(TH)
              DO 2 I=2,NPT
              IY(I)=INT((Y(I)-YMIN)*YS+.5+(FLOAT(I-1)*RS*B))+IY11
        2     CONTINUE
              RETURN
              END

    ROUTINES CALLED:
    MAXMIN, FLOAT  , INT    , ATAN2 , SQRT  , SIN

    OPTIONS =/CK:3

    BLOCK          LENGTH
    CRD11    322     (001204)*

    **COMPILER ----- CORE**
       PHASE        USED  FREE
    DECLARATIVES  00622 14756
    EXECUTABLES   00943 14435
    ASSEMBLY      01137 19281
```

```
      SUBROUTINE LLKBP(X,IYC,NPT,IX1,IX2,IY11,IY21,KK)
      DIMENSION X(NPT),IYC(NPT)
      CALL INITT(0)
      CALL MAXMIN(X,XMAX,XMIN,NPT)
      XS=FLOAT(IX2-IX1)/(XMAX-XMIN)
      IX=INT((X(1)-XMIN)*XS+.5)-IX1
      CALL MOVABS(IX1,IY11)
      CALL DRWABS(IX,IYC(1))
      DO 2 I=2,NPT
      IX=INT((X(I)-XMIN)*XS+.5)-IX1
      IF(IYC(I).LT.0)CALL MOVABS(IX,IABS(IYC(I)))
      IF(IYC(I).GT.0)CALL DRWABS(IX,IYC(I))
2     CONTINUE
      IF(KK.GT.1)GO TO 3
      CALL DRWABS(IX2,IY21)
      CALL DRWABS(IX1,IY11)
3     CALL FINITT(0,780)
      RETURN
      END
```

ROUTINES CALLED:
INITT , MAXMIN, FLOAT , INT , MOVABS, DRWABS, IABS
FINITT

OPTIONS =/OP:2

BLOCK	LENGTH	
LLKBP	332	(001230)*

COMPILER ----- CORE

PHASE	USED	FREE
DECLARATIVES	00622	14756
EXECUTABLES	00863	14515
ASSEMBLY	01153	18865

```
      SUBROUTINE MAXMIN(Y,YMAX,YMIN,NPT)
      REAL Y(NPT)
      YMAX=Y(1)
      YMIN=Y(1)
      DO 10 I=2,NPT
      IF(Y(I).GT.YMAX)YMAX=Y(I)
      IF(Y(I).LT.YMIN)YMIN=Y(I)
10    CONTINUE
      RETURN
      END
```

```
OPTIONS =/OP:2

BLOCK        LENGTH
MAXMIN   105      (000322)*

**COMPILER ----- CORE**
   PHASE        USED  FREE
DECLARATIVES 00622 14756
EXECUTABLES  00707 14675
ASSEMBLY     00937 15031
```

```
      SUBROUTINE CHCU(IX,IY,IXX,IYY,I,RATE,KK,IH)
      INTEGER IX(1),IY(1),IXX(1),IYY(1)
      DX=FLOAT(IX(5)-IX(1))
      DY=FLOAT(IY(5)-IY(1))
      DZ=SQRT(DX*DX+DY*DY)
      DZS=DZ/FLOAT(KK)
      TH=ATAN2(DY,DX)
      A=COS(TH)
      B=SIN(TH)
      IC=INT(RATE*FLOAT(IH))
      IXX(1)=INT(FLOAT(IX(1))+FLOAT(I-1)*A*DZS)
      IYY(1)=INT(FLOAT(IY(1))+FLOAT(I-1)*B*DZS)
      IXX(2)=IXX(1)
      IYY(2)=IYY(1)+IC
      IXX(3)=INT(FLOAT(IX(3))+FLOAT(I-1)*A*DZS)
      IYY(3)=INT(FLOAT(IY(3))+FLOAT(I-1)*B*DZS)
      IXX(4)=IXX(3)
      IYY(4)=IYY(3)+IC
      RETURN
      END
```

```
ROUTINES CALLED:
FLOAT , SQRT   , ATAN2 , COS    , SIN    , INT

OPTIONS =/OP 2

BLOCK          LENGTH
CHCU     459     (001626)*

**COMPILER ----- CORE**
   PHASE         USED  FREE
DECLARATIVES   00622 14756
EXECUTABLES    00943 14435
ASSEMBLY       01125 18893
```

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